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Castro, Miguel Nobre; Zhou, Lelai; Bai, Shaoping; Andersen, Michael Skipper; Rasmussen, John

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OVERCOMING BRACHIALIS PLEXUS INJURIES USING A PASSIVE ORTHOSIS

¹Miguel Nobre Castro, ¹Lelai Zhou, ¹Shaoping Bai, ¹Michael Skipper Andersen, ¹John Rasmussen

¹AnyBody Research Group, Department of Mechanical and Manufacturing Engineering, Aalborg University
Email: {mnc, lzh, shb, msa, jr} @m-tech.aau.dk

INTRODUCTION

Brachialis plexus injuries typically caused by falls or traffic accidents result in total or partial loss of upper limb function due to permanent lesion of neural pathways, more precisely cervical C5-C8 and thoracic T1 nerves. Thus, the transmission of nervous signals from the spinal cord to the upper limbs is interrupted, resulting in paralysis [1].

Both passive and active arm assistive devices can be found in literature [2]. The concept behind the latter group is to assist the patient with counteracting the external loads (e.g. the gravitational force) using only passive elements and hence does not require actuators or complex control algorithms [3].

The design of a spring-loaded, cable-driven, wearable passive orthosis with four degree-of-freedom is presented here on the basis of simulation of the human body-orthosis interactions through a comprehensive musculoskeletal model.

METHODS

The orthosis is composed of three components (Figure 1): the armor cuff and the elbow upper and lower brackets. Five cables (three for the shoulder joint and two connecting the elbow upper and lower brackets) are linked to individual pre-loaded springs in an array box, which is anchored to the back of the armor part. According to the gravity-balancing principle [3], both springs' stiffness and pre-load forces can be defined as design parameters for the formulation of an optimization process of the orthosis design [4]. The orthosis model is built in SolidWorks (Dassault Systèmes SolidWorks Corp., Massachusetts, USA).

Given the aim of the orthosis to exploit the residual muscle activity in patients' arms, the mechanics of the human body-orthosis interactions was formulated and solved with the AnyBody Modeling System (AMS) (AnyBody Technology A/S, Aalborg, Denmark). The orthosis model was imported to AMS and its armor part considered fixed to the trunk of the human model. The attachment of the upper bracket to the upper arm was modelled as a revolute joint. The lower bracket was connected to the lower arm through a translation-spherical joint, allowing the lower bracket to rotate around the pronation axis of the forearm.

By disabling paralyzed muscles, the musculoskeletal model can compute the muscle activations for different nerve lesion conditions. Therefore, a patient-specific brachialis plexus injury can be simulated and the design parameters of the orthosis computed from a maximal muscle activation (MMACT) minimization point-of-view [5]. The motion data of picking up a cup was captured using two Kinect™ sensors [6], while a 0.5 kg payload was carried the hand and used as the design case.

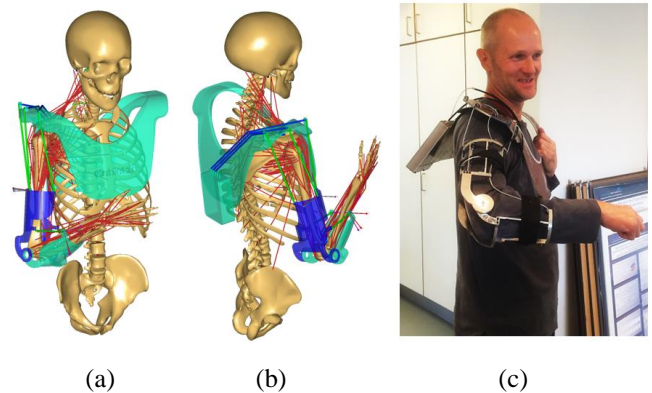


Figure 1: Musculoskeletal model including orthosis: (a) front-view; (b) rear-view. (c) Subject wearing the passive orthosis aluminium prototype.

RESULTS AND DISCUSSION

If the muscle activity of any muscle exceeds 1, that muscle has insufficient strength to complete the required motion. It was found that injuries in nerves C5 or C6, which disable most of the upper arm muscles, are the most critical leading to very high MMACT values. The tested model with a C7 lesion revealed that the MMACT values were always below 1 during motion after optimization, and the respective orthosis optimal spring stiffness were $k_{gh1-5} = [1473.4, 0.3, 0.03, 102.0, 1979.0]$ N/m. The model with a C7 lesion is, hence, predicted capable of perform that motion, when wearing the orthosis.

CONCLUSIONS

The presented orthosis design is a proof-of-concept of the simulation-based approach. The next steps are improvement of mechanical details and experimental validation. Furthermore, since the orthosis only compensates gravity, active exoskeleton strategies might be useful to enable the patient to handle heavier objects. Both wearability and aesthetics must be improved, for instance by use of light-weight materials and 3-D printing.

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